PATENT ABSTRACTS OF JAPAN

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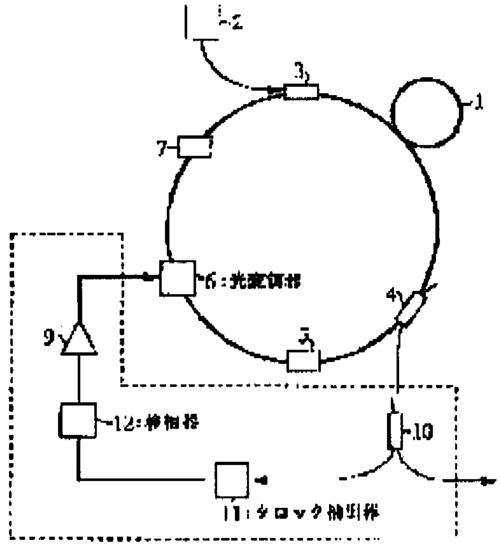
(54) LASER PULSE OSCILLATOR

(57)Abstract:
PURPOSE: To provide a laser pulse oscillator for generating extremely stabilized optical pulse in the higher repetitive frequency for a longe period of time.
CONSTITUTION: In a harmonic mode synchronous laser pulse oscillator where the modulation frequency of an optical modulator 6 provided within a laser resonator is set to an integer multiple the basic frequency determined depending on the loop length of the laser resonator, a clock signal corresponding to the repetition frequency is extracted, by means of a clock extraction circuit 11 composed of a light receiving element and a narrow band filter, from a part of the output laser of such laser pulse oscillator and this clock signal drives an optical modulator 6.



CLAIMS

[Claim(s)]
[Claim 1]A laser pulse oscillator which is constituted by loop having the following and supplying said optical modulator by making this clock signal into a modulating signal, and having contained an optical modulator, and outputs a laser pulse of repeat frequency of an integral multiple of fundamental frequency corresponding to loop length of this loop.
A photo detector which changes into an electrical signal a laser pulse obtained from said loop.
A narrow band filter which extracts a clock signal of frequency of an integral multiple of said fundamental frequency from this electrical signal.

[Claim 2]The laser pulse oscillator according to claim 1 by which an optical fiber for optical-pulse compression being included in said loop

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application]This invention relates to the laser pulse oscillator made to generate stably a laser pulse with high repeat frequency which is needed, for example in order to build an ultra high-speed optical fiber communications system.
[0002]
[Description of the Prior Art]In recent years, research which generates a laser pulse with high repeat frequency is briskly done by the optical fiber laser using mode locking art. Drawing 4 is an example of the lineblock diagram of the conventional laser pulse oscillator. The optical fiber in which 1 added the rare earth element in the figure (it is described as rare earth doped optical fiber below), The excitation light source for 2 to excite rare earth doped optical fiber, the optical coupling machine with which 3 combines excitation light with rare earth doped optical fiber, As for an optical modulator and 7, a synthesizer and 9 are electrical amplification machines an optical filter and 8 the light branching machine for which 4 takes out an output, the optical isolator for which 5 restricts the direction of movement of light in the one direction, and 6.
[0003]In this laser pulse oscillator, the lightwave pulse with high repeat frequency is generated as follows. If the rare earth doped optical fiber 1 is excited by the excitation light source 2 through the optical coupling machine 3, the oscillation of continuation light will take place to the forward direction of the optical isolator 5 in the transmission band of the optical filter 7. Next, it lets the electrical amplification machine 9 pass, and the electrical signal outputted from the synthesizer 8 is impressed to the optical intensity modulator 6. Generally, if the refractive index of L and an optical fiber is set to n and the velocity of light is set to c, cavity length (the loop length of this laser pulse oscillator), When abnormal conditions are added by fundamental frequency $f_0=c/(nL)$ decided by cavity length, the mode locking in fundamental frequency f_0 is

realized, and a stable optical pulse train can be generated.
[0004]If q times of fundamental frequency f_0 decided by cavity length of laser and $qf_0=qc/(nL)$ (q set modulation frequency as integer), the forced mode locking of the harmonics oscillated by one q times the frequency of a fundamental wave is realizable. That is, q lightwave pulses are made at equal intervals in the resonator of laser, and an optical pulse train with the repetition which was in agreement with high order modulation frequency occurs. This optical pulse train is outputted through the light branching machine 4. For example, when the cavity length of laser is 200 m, fundamental frequency f_0 decided by cavity length is 1 MHz, but if modulation frequency is set to q= 10000 and set as 10 GHz, an optical pulse train with a 10-GHz repetition will occur.
[0005]
[Problem(s) to be Solved by the Invention]However, in this conventional laser pulse oscillator, cavity length is changed by the temperature change in a laser cavity, and a fundamental wave changes with time as the result. Since the repetition of the high order modulating signal impressed on the other hand was set as constant value, it was difficult for both repetition not to be in agreement and to generate an optical pulse train stably over a long time.
[0006]Here, the temperature in a laser cavity considers the case where only deltat changes. If temperature changes only deltat, optical fiber length will change only deltaL. In this case, deltaL is given by the following formula.
delta L/L=alphadeltat (1)
However, L is the cavity length of the laser before a temperature change, and alpha is a coefficient of linear expansion of an optical fiber. By a temperature change, change of the cavity length of laser will change fundamental frequency f_0 decided by cavity length. It stops being in agreement q times of fundamental frequency f_0, the waveform of a lightwave pulse is distorted, and it becomes impossible in this case, for modulation frequency to realize harmonics mode locking. If frequency f ($=qf_0$) is made into the modulation frequency before a temperature change, frequency change deltaf will be given by the following formula.
delta f/f=delta t/L=alphadeltat (2)
When temperature changes, it is necessary only for deltaf to change modulation frequency to attaining harmonics mode locking. Frequency change deltaf becomes so large that the modulation frequency f becomes large (i.e., so that the value of q becomes large). That is, the thing of the frequency by a temperature change which variation becomes large and acquires for an optical pulse train stably over a long period of time absolutely is more difficult for higher order harmonics mode locking.
[0007]For example, in the above-mentioned conventional laser pulse oscillator, when the temperature in a resonator changes 0.01 degree, if L= 200 m, f= 10 GHz, and alpha=10^{-5}, it will be set to deltaL=20micrometer and deltaf=1kHz from (1) and (2) types. That is, a big frequency change arises in few temperature changes, and the waveform of a lightwave pulse deteriorates. In order to obtain a stable optical pulse train, only deltaf needs to change modulation frequency and it needs to be 10.0001 GHz. In order to realize this, the active negative feedback circuit which adjusts the length of a resonator automatically is needed.
[0008]In harmonics mode locking, since abnormal conditions are applied by q times of fundamental frequency f_0 decided by cavity length, if q becomes large, it will become difficult to control thoroughly the spectral component of the vertical microfiche decided by fundamental

frequency f_0. For example, it is referred to as f_0=1MHz and f= 10 GHz, and a light spectrum when the conventional laser pulse oscillator performs harmonics mode locking is shown in drawing 5. In a figure, although there is an ingredient with the strongest intensity every 10 GHz, there is a spectral component of the weak vertical microfiche decided by fundamental frequency f_0 besides it. Since the spectral component of vertical microfiche other than this modulation frequency is not controlled, while the gap with modulation frequency and cavity length occurs, the oscillation of laser is made unstable and it makes it difficult to generate a lightwave pulse stably.

[0009]As mentioned above, in the Prior art, although the optical pulse train with high repeat frequency was generated when harmonics mode locking was performed, it was difficult for a pulse shape to deteriorate by the temperature change in a resonator for a short time, and to generate stably an optical pulse train with high repeat frequency over a long time. in order to perform light modulation -- high -- the stable synthesizer was needed.

[0010]This invention was made in view of such a situation, and does not need the synthesizer or the active negative feedback circuit of high frequency in harmonics mode locking, but an object of this invention is to provide the laser pulse oscillator made to generate very stably an optical pulse train with high repeat frequency over a long time.

[0011]

[Means for Solving the Problem]In order that the laser pulse oscillator according to claim 1 may solve an aforementioned problem, In a laser pulse oscillator which is constituted by loop having contained an optical modulator and outputs a laser pulse of repeat frequency of an integral multiple of fundamental frequency corresponding to loop length of this loop, It has a photo detector which changes into an electrical signal a laser pulse obtained from said loop, and a narrow band filter which extracts a clock signal of frequency of an integral multiple of said fundamental frequency from this electrical signal, and said optical modulator is supplied by making this clock signal into a modulating signal.

[0012]The laser pulse oscillator according to claim 2 contains an optical fiber for optical-pulse compression in a loop in the laser pulse oscillator according to claim 1.

[0013]

[Function]According to the laser pulse oscillator according to claim 1, a photo detector changes into an electrical signal the laser pulse to which repeat frequency is changed arbitrarily. A narrow band filter extracts the clock signal of the frequency of the integral multiple of said fundamental frequency from this electrical signal. And the optical modulator within a loop carries out intensity modulation of the laser pulse by making this clock signal into a modulating signal. Even if cavity length changes with temperature changes and the repeat frequency of a laser pulse changes with these, an optical modulator can be driven the optimal on the frequency which followed in footsteps of a repetition [a laser pulse]. Therefore, there is no degradation of a laser pulse waveform by a temperature change, and the oscillation of a laser pulse continues stably over a long time.

[0014]According to the laser pulse oscillator according to claim 2, pulse width of the laser pulse generated using the effect of an optical soliton can be shortened.

[0015]

[Example]Hereafter, with reference to drawing 1 thru/or drawing 3, one example of the laser

pulse oscillator by this invention is described in detail. However, identical codes were given to the composition and identical parts which were shown in drawing 4. Drawing 1 is a figure showing the composition of the laser pulse oscillator of this example. In a figure, a laser pulse oscillator, The rare earth doped optical fiber 1 and the rare earth doped optical fiber 1. The excitation light source 2 for exciting, and excitation light. It comprises the optical coupling machine 3 combined with the rare earth doped optical fiber 1, the light branching machine 4 which takes out an output, the optical isolator 5 which restricts the direction of movement of light in the one direction, the optical modulator 6, the optical filter 7, the light branching machine 10, the clock extraction machine 11, the phase converter 12, and the electrical amplification machine 9.

[0016]The clock extraction machine 11 comprises a photo detector which changes the inputted laser pulse into an electrical signal, a narrow band filter in which main passing frequency was set as 10 GHz, and an electrical amplification machine which amplifies the output of this narrow band filter. Here, the loop length of the laser pulse oscillator of this example is set up so that fundamental frequency f_0 may be set to 1 MHz. The main passing frequency of the narrow band filter is set as 10 GHz so that the clock extraction machine 11 may output the laser pulse it is 10 GHz, whose 10000 times, i.e., repeat frequency, of fundamental frequency f_0.

[0017]The phase converter 12 adjusts the phase of the output signal of the clock extraction machine 11. The electrical amplification machine 9 amplifies the output signal of the phase converter 12, and supplies it to the optical modulator 6. The optical modulator 6 is an intensity modulation machine.

For example, the Mach-Zehnder type intensity modulation machine made from lithium niobate, etc. can be used.

That is, as the dotted line of drawing 1 shows, a closed loop consists of laser pulse oscillators of this example from the clock extraction machine 11 to the optical modulator 6. If an erbium-doped optical fiber is used as the rare earth doped optical fiber 1, the oscillation wavelength of laser will serve as a 1.5-micrometer belt. A semiconductor laser can be used as the excitation light source 2.

[0018]Next, generating of an optical pulse train with high repeat frequency in the laser pulse oscillator of the above-mentioned composition is explained. If the rare earth doped optical fiber 1 is excited by the excitation light source 2 through an optical coupling machine, the oscillation of a continuous laser beam will take place to the forward direction of the optical isolator 5 in the transmission band of the optical filter 7. This laser beam is taken out through the light branching machine 4, it divides with the light branching machine 10 further, and that part is inputted into the clock extraction machine 11. The clock extraction machine 11 extracts the clock signal by the vertical microfiche near 10 GHz. After phase adjustment of this clock signal is carried out in the phase converter 12 and it is amplified with the electrical amplification machine 9, it is supplied to the optical modulator 6 as a modulating signal. With this clock signal, the optical modulator 6 carries out intensity modulation of the laser beam, and outputs a laser pulse.

[0019]Here, since the clock signal by the vertical microfiche near [conflicting q times of fundamental frequency f_0 decided by loop length of a resonator] 10 GHz cannot generate a stable optical pulse train, it is extinguished in a clock extraction process. However, since the repetition of modulation frequency and a lightwave pulse of the clock signals [congruous q

times of fundamental frequency f_0] corresponds thoroughly, the oscillation of a stable lightwave pulse is strengthened gradually. If this is repeated, only the clock signal near [congruous q times of fundamental frequency f_0 which was noise-like at first / one certain] 10 GHz will remain. That is, it comes to drive the optical modulator 6 only with one clock signal which controlled excessive vertical microfiche, and 10-GHz harmonics mode locking is attained.

[0020]At this time, as shown in drawing 2, pulse width of the lightwave pulse generated using the effect of an optical soliton can be shortened by inserting the optical fiber 13 for optical-pulse compression between the rare earth doped optical fiber 1 and the light branching machine 4, for example. Here, an optical soliton is explained. An optical soliton is a stable lightwave pulse generated by the breadth of the pulse width by negative distribution of an optical fiber and compression of the pulse width by the self-phase modulation effect hanging, and suiting, and it has [the inside of an optical fiber] the feature, alias a frog, and of spreading there being nothing for the waveform. Peak intensity $P_{N=1}$ required to make the standard soliton of N= 1 is given by the following formula.

$P_{N=1}$=0.776pilambda^{3}w^2|D|/pi^{2}c$n_2$tau^2 (3)

As for the velocity of light and n_2, pulse width and w of a nonlinear refractive index and tau are [group velocity dispersion / in / in D / the wavelength lambda of an optical fiber /, and c] the sizes of the spot size of an optical fiber here.

[0021]That is, by making negative group velocity dispersion D of the optical fiber 13 for optical-pulse compression, an optical soliton is generated and the lightwave pulse in which pulse width does not spread can be obtained. For example, if it is group-velocity-dispersion D=-3 ps/km/nm, pulse width tau=3ps, a size of w= 3 micrometers of spot size, and the wavelength of lambda= 1.55 micrometers, peak intensity required to make a standard optical soliton will be set to about 290 mW from (3) types. If a repetition of a lightwave pulse shall be 10 GHz, the mean intensity in a resonator will be set to about 8.7 mW. Intensity of this level can be easily generated within the laser pulse oscillator by this example. That is, when the variance in the wavelength of 1.55 micrometers uses the dispersion shifted fiber which is -3 ps/km/nm as the optical fiber 13 for optical-pulse compression, pulse width can generate stably the optical pulse train which is 3ps in a 10-GHz repetition. What is necessary is just to change the frequency of the clock signal extracted with the clock extraction machine 11, in order to change the repeat frequency of this intensity-of-light pulse.

[0022]In the laser pulse oscillator of this example, even if cavity length changes with temperature changes and a repetition of a lightwave pulse changes, in order to become irregular with the clock signal in sync with a repetition of a lightwave pulse, a gap does not arise between repetitions of modulation frequency and a lightwave pulse. Therefore, unlike a Prior art, it has the feature with which the waveform of a lightwave pulse does not deteriorate by a temperature change. However, the repetition of a lightwave pulse is changing slightly according to change of cavity length. That is, it is not dependent on the temperature change in a resonator, harmonics mode locking is always maintained, and the laser pulse oscillator of this example can generate an optical pulse train with stable high repeat frequency over a long time. Since the active negative feedback circuit for stabilization of the highly precise synthesizer and resonator which were furthermore needed conventionally becomes unnecessary, an economical advantage is also large.

[0023]Since the oscillation repeat frequency of laser and the modulation frequency impressed to

a modulator are thoroughly [always] in agreement when performing harmonics mode locking, excessive vertical microfiche other than modulation frequency can be controlled thoroughly. For example, the electric spectrum at the time of performing harmonics mode locking is shown in drawing 3 as f_0=1MHz and f= 10 GHz. Only 10-GHz modulation frequency components exist in a figure. Thus, since excessive vertical microfiche other than modulation frequency can control thoroughly, the stable harmonics mode locking can be realized and a very stable optical pulse train with high repeat frequency can be generated.
[0024]
[Effect of the Invention]As mentioned above, in the laser pulse oscillator made to generate an optical pulse train with high repeat frequency by harmonics mode locking in this invention as explained, Without needing the highly precise synthesizer needed conventionally, the clock signal of the sine wave corresponding to repeat frequency is extracted from a part of output of laser, and an optical modulator is driven with the frequency.
Therefore, an optical pulse train with very stable high repeat frequency can be generated over a long time.
It is possible by inserting the optical fiber for optical-pulse compression into a laser cavity to generate a lightwave pulse with short pulse width still more stably.

TECHNICAL FIELD

[Industrial Application]This invention relates to the laser pulse oscillator made to generate stably a laser pulse with high repeat frequency which is needed, for example in order to build an ultra high-speed optical fiber communications system.

PRIOR ART

[Description of the Prior Art]In recent years, research which generates a laser pulse with high repeat frequency is briskly done by the optical fiber laser using mode locking art. Drawing 4 is an example of the lineblock diagram of the conventional laser pulse oscillator. The optical fiber in which 1 added the rare earth element in the figure (it is described as rare earth doped optical fiber below), The excitation light source for 2 to excite rare earth doped optical fiber, the optical coupling machine with which 3 combines excitation light with rare earth doped optical fiber, As for an optical modulator and 7, a synthesizer and 9 are electrical amplification machines an optical filter and 8 the light branching machine for which 4 takes out an output, the optical isolator for which 5 restricts the direction of movement of light in the one direction, and 6.
[0003]In this laser pulse oscillator, the lightwave pulse with high repeat frequency is generated as follows. If the rare earth doped optical fiber 1 is excited by the excitation light source 2 through the optical coupling machine 3, the oscillation of continuation light will take place to the forward direction of the optical isolator 5 in the transmission band of the optical filter 7. Next, it

lets the electrical amplification machine 9 pass, and the electrical signal outputted from the synthesizer 8 is impressed to the optical intensity modulator 6. Generally, if the refractive index of L and an optical fiber is set to n and the velocity of light is set to c, cavity length (the loop length of this laser pulse oscillator), When abnormal conditions are added by fundamental frequency $f_0=c/(nL)$ decided by cavity length, the mode locking in fundamental frequency f_0 is realized, and a stable optical pulse train can be generated.
[0004]If q times of fundamental frequency f_0 decided by cavity length of laser and $qf_0=qc/(nL)$ (q set modulation frequency as integer), the forced mode locking of the harmonics oscillated by one q times the frequency of a fundamental wave is realizable. That is, q lightwave pulses are made at equal intervals in the resonator of laser, and an optical pulse train with the repetition which was in agreement with high order modulation frequency occurs. This optical pulse train is outputted through the light branching machine 4. For example, when the cavity length of laser is 200 m, fundamental frequency f_0 decided by cavity length is 1 MHz, but if modulation frequency is set to q= 10000 and set as 10 GHz, an optical pulse train with a 10-GHz repetition will occur.

EFFECT OF THE INVENTION

[Effect of the Invention]As mentioned above, in the laser pulse oscillator made to generate an optical pulse train with high repeat frequency by harmonics mode locking in this invention as explained, Without needing the highly precise synthesizer needed conventionally, the clock signal of the sine wave corresponding to repeat frequency is extracted from a part of output of laser, and an optical modulator is driven with the frequency.
Therefore, an optical pulse train with very stable high repeat frequency can be generated over a long time.
It is possible by inserting the optical fiber for optical-pulse compression into a laser cavity to generate a lightwave pulse with short pulse width still more stably.

TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention]However, in this conventional laser pulse oscillator, cavity length is changed by the temperature change in a laser cavity, and a fundamental wave changes with time as the result. Since the repetition of the high order modulating signal impressed on the other hand was set as constant value, it was difficult for both repetition not to be in agreement and to generate an optical pulse train stably over a long time.
[0006]Here, the temperature in a laser cavity considers the case where only deltat changes. If temperature changes only deltat, optical fiber length will change only deltaL. In this case, deltaL is given by the following formula.
delta L/L=alphadeltat (1)
However, L is the cavity length of the laser before a temperature change, and alpha is a

coefficient of linear expansion of an optical fiber. By a temperature change, change of the cavity length of laser will change fundamental frequency f_0 decided by cavity length. It stops being in agreement q times of fundamental frequency f_0, the waveform of a lightwave pulse is distorted, and it becomes impossible in this case, for modulation frequency to realize harmonics mode locking. If frequency f (=qf_0) is made into the modulation frequency before a temperature change, frequency change deltaf will be given by the following formula.
delta f/f=delta t/L=alphadeltat (2)
When temperature changes, it is necessary only for deltaf to change modulation frequency to attaining harmonics mode locking. Frequency change deltaf becomes so large that the modulation frequency f becomes large (i.e., so that the value of q becomes large). That is, the thing of the frequency by a temperature change which variation becomes large and acquires for an optical pulse train stably over a long period of time absolutely is more difficult for higher order harmonics mode locking.
[0007]For example, in the above-mentioned conventional laser pulse oscillator, when the temperature in a resonator changes 0.01 degree, if L= 200 m, f= 10 GHz, and alpha=10^{-5}, it will be set to deltaL=20micrometer and deltaf=1kHz from (1) and (2) types. That is, a big frequency change arises in few temperature changes, and the waveform of a lightwave pulse deteriorates. In order to obtain a stable optical pulse train, only deltaf needs to change modulation frequency and it needs to be 10.0001 GHz. In order to realize this, the active negative feedback circuit which adjusts the length of a resonator automatically is needed.
[0008]In harmonics mode locking, since abnormal conditions are applied by q times of fundamental frequency f_0 decided by cavity length, if q becomes large, it will become difficult to control thoroughly the spectral component of the vertical microfiche decided by fundamental frequency f_0. For example, it is referred to as f_0=1MHz and f= 10 GHz, and a light spectrum when the conventional laser pulse oscillator performs harmonics mode locking is shown in drawing 5. In a figure, although there is an ingredient with the strongest intensity every 10 GHz, there is a spectral component of the weak vertical microfiche decided by fundamental frequency f_0 besides it. Since the spectral component of vertical microfiche other than this modulation frequency is not controlled, while the gap with modulation frequency and cavity length occurs, the oscillation of laser is made unstable and it makes it difficult to generate a lightwave pulse stably.
[0009]As mentioned above, in the Prior art, although the optical pulse train with high repeat frequency was generated when harmonics mode locking was performed, it was difficult for a pulse shape to deteriorate by the temperature change in a resonator for a short time, and to generate stably an optical pulse train with high repeat frequency over a long time. in order to perform light modulation -- high -- the stable synthesizer was needed.
[0010]This invention was made in view of such a situation, and does not need the synthesizer or the active negative feedback circuit of high frequency in harmonics mode locking, but an object of this invention is to provide the laser pulse oscillator made to generate very stably an optical pulse train with high repeat frequency over a long time.

MEANS

[Means for Solving the Problem]In order that the laser pulse oscillator according to claim 1 may solve an aforementioned problem, In a laser pulse oscillator which is constituted by loop having contained an optical modulator and outputs a laser pulse of repeat frequency of an integral multiple of fundamental frequency corresponding to loop length of this loop, It has a photo detector which changes into an electrical signal a laser pulse obtained from said loop, and a narrow band filter which extracts a clock signal of frequency of an integral multiple of said fundamental frequency from this electrical signal, and said optical modulator is supplied by making this clock signal into a modulating signal.
[0012]The laser pulse oscillator according to claim 2 contains an optical fiber for optical-pulse compression in a loop in the laser pulse oscillator according to claim 1.

OPERATION

[Function]According to the laser pulse oscillator according to claim 1, a photo detector changes into an electrical signal the laser pulse to which repeat frequency is changed arbitrarily. A narrow band filter extracts the clock signal of the frequency of the integral multiple of said fundamental frequency from this electrical signal. And the optical modulator within a loop carries out intensity modulation of the laser pulse by making this clock signal into a modulating signal. Even if cavity length changes with temperature changes and the repeat frequency of a laser pulse changes with these, an optical modulator can be driven the optimal on the frequency which followed in footsteps of a repetition [a laser pulse]. Therefore, there is no degradation of a laser pulse waveform by a temperature change, and the oscillation of a laser pulse continues stably over a long time.
[0014]According to the laser pulse oscillator according to claim 2, pulse width of the laser pulse generated using the effect of an optical soliton can be shortened.

EXAMPLE

[Example]Hereafter, with reference to drawing 1 thru/or drawing 3, one example of the laser pulse oscillator by this invention is described in detail. However, identical codes were given to the composition and identical parts which were shown in drawing 4. Drawing 1 is a figure showing the composition of the laser pulse oscillator of this example. In a figure, a laser pulse oscillator, The rare earth doped optical fiber 1 and the rare earth doped optical fiber 1. The excitation light source 2 for exciting, and excitation light. It comprises the optical coupling machine 3 combined with the rare earth doped optical fiber 1, the light branching machine 4 which takes out an output, the optical isolator 5 which restricts the direction of movement of light in the one direction, the optical modulator 6, the optical filter 7, the light branching machine

10, the clock extraction machine 11, the phase converter 12, and the electrical amplification machine 9.

[0016]The clock extraction machine 11 comprises a photo detector which changes the inputted laser pulse into an electrical signal, a narrow band filter in which main passing frequency was set as 10 GHz, and an electrical amplification machine which amplifies the output of this narrow band filter. Here, the loop length of the laser pulse oscillator of this example is set up so that fundamental frequency f_0 may be set to 1 MHz. The main passing frequency of the narrow band filter is set as 10 GHz so that the clock extraction machine 11 may output the laser pulse it is 10 GHz, whose 10000 times, i.e., repeat frequency, of fundamental frequency f_0.

[0017]The phase converter 12 adjusts the phase of the output signal of the clock extraction machine 11. The electrical amplification machine 9 amplifies the output signal of the phase converter 12, and supplies it to the optical modulator 6. The optical modulator 6 is an intensity modulation machine.

For example, the Mach-Zehnder type intensity modulation machine made from lithium niobate, etc. can be used.

That is, as the dotted line of drawing 1 shows, a closed loop consists of laser pulse oscillators of this example from the clock extraction machine 11 to the optical modulator 6. If an erbium-doped optical fiber is used as the rare earth doped optical fiber 1, the oscillation wavelength of laser will serve as a 1.5-micrometer belt. A semiconductor laser can be used as the excitation light source 2.

[0018]Next, generating of an optical pulse train with high repeat frequency in the laser pulse oscillator of the above-mentioned composition is explained. If the rare earth doped optical fiber 1 is excited by the excitation light source 2 through an optical coupling machine, the oscillation of a continuous laser beam will take place to the forward direction of the optical isolator 5 in the transmission band of the optical filter 7. This laser beam is taken out through the light branching machine 4, it divides with the light branching machine 10 further, and that part is inputted into the clock extraction machine 11. The clock extraction machine 11 extracts the clock signal by the vertical microfiche near 10 GHz. After phase adjustment of this clock signal is carried out in the phase converter 12 and it is amplified with the electrical amplification machine 9, it is supplied to the optical modulator 6 as a modulating signal. With this clock signal, the optical modulator 6 carries out intensity modulation of the laser beam, and outputs a laser pulse.

[0019]Here, since the clock signal by the vertical microfiche near [conflicting q times of fundamental frequency f_0 decided by loop length of a resonator] 10 GHz cannot generate a stable optical pulse train, it is extinguished in a clock extraction process. However, since the repetition of modulation frequency and a lightwave pulse of the clock signals [congruous q times of fundamental frequency f_0] corresponds thoroughly, the oscillation of a stable lightwave pulse is strengthened gradually. If this is repeated, only the clock signal near [congruous q times of fundamental frequency f_0 which was noise-like at first / one certain] 10 GHz will remain. That is, it comes to drive the optical modulator 6 only with one clock signal which controlled excessive vertical microfiche, and 10-GHz harmonics mode locking is attained.

[0020]At this time, as shown in drawing 2, pulse width of the lightwave pulse generated using the effect of an optical soliton can be shortened by inserting the optical fiber 13 for optical-pulse compression between the rare earth doped optical fiber 1 and the light branching machine 4, for

example. Here, an optical soliton is explained. An optical soliton is a stable lightwave pulse generated by the breadth of the pulse width by negative distribution of an optical fiber and compression of the pulse width by the self-phase modulation effect hanging, and suiting, and it has [the inside of an optical fiber] the feature, alias a frog, and of spreading there being nothing for the waveform. Peak intensity $P_{N=1}$ required to make the standard soliton of N= 1 is given by the following formula.
$P_{N=1}$=0.776pilambda^{3}w^2|D|/pi^{2}cn$_2$tau^2 (3)
As for the velocity of light and n_2, pulse width and w of a nonlinear refractive index and tau are [group velocity dispersion / in / in D / the wavelength lambda of an optical fiber /, and c] the sizes of the spot size of an optical fiber here.
[0021]That is, by making negative group velocity dispersion D of the optical fiber 13 for optical-pulse compression, an optical soliton is generated and the lightwave pulse in which pulse width does not spread can be obtained. For example, if it is group-velocity-dispersion D=-3 ps/km/nm, pulse width tau=3ps, a size of w= 3 micrometers of spot size, and the wavelength of lambda= 1.55 micrometers, peak intensity required to make a standard optical soliton will be set to about 290 mW from (3) types. If a repetition of a lightwave pulse shall be 10 GHz, the mean intensity in a resonator will be set to about 8.7 mW. Intensity of this level can be easily generated within the laser pulse oscillator by this example. That is, when the variance in the wavelength of 1.55 micrometers uses the dispersion shifted fiber which is -3 ps/km/nm as the optical fiber 13 for optical-pulse compression, pulse width can generate stably the optical pulse train which is 3ps in a 10-GHz repetition. What is necessary is just to change the frequency of the clock signal extracted with the clock extraction machine 11, in order to change the repeat frequency of this intensity-of-light pulse.
[0022]In the laser pulse oscillator of this example, even if cavity length changes with temperature changes and a repetition of a lightwave pulse changes, in order to become irregular with the clock signal in sync with a repetition of a lightwave pulse, a gap does not arise between repetitions of modulation frequency and a lightwave pulse. Therefore, unlike a Prior art, it has the feature with which the waveform of a lightwave pulse does not deteriorate by a temperature change. However, the repetition of a lightwave pulse is changing slightly according to change of cavity length. That is, it is not dependent on the temperature change in a resonator, harmonics mode locking is always maintained, and the laser pulse oscillator of this example can generate an optical pulse train with stable high repeat frequency over a long time. Since the active negative feedback circuit for stabilization of the highly precise synthesizer and resonator which were furthermore needed conventionally becomes unnecessary, an economical advantage is also large.
[0023]Since the oscillation repeat frequency of laser and the modulation frequency impressed to a modulator are thoroughly [always] in agreement when performing harmonics mode locking, excessive vertical microfiche other than modulation frequency can be controlled thoroughly. For example, the electric spectrum at the time of performing harmonics mode locking is shown in drawing 3 as f_0=1MHz and f= 10 GHz. Only 10-GHz modulation frequency components exist in a figure. Thus, since excessive vertical microfiche other than modulation frequency can control thoroughly, the stable harmonics mode locking can be realized and a very stable optical pulse train with high repeat frequency can be generated.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1]It is a figure showing the 1st example of composition of the laser pulse oscillator of this invention.

[Drawing 2]It is a figure showing the 2nd example of composition of the laser pulse oscillator of this invention.

[Drawing 3]It is a figure showing the situation of the electric spectrum in the laser pulse oscillator of this invention.

[Drawing 4]It is a figure showing the composition of the conventional laser pulse oscillator.

[Drawing 5]It is a figure showing the appearance of the light spectrum in the conventional laser pulse oscillator.

[Description of Notations]

1 Rare earth doped optical fiber

2 The excitation light source for exciting rare earth doped optical fiber

3 The optical coupling machine which combines excitation light with rare earth doped optical fiber

4 The light branching machine which takes out an output

5 The optical isolator which restricts the direction of movement of light in the one direction

6 Optical modulator

7 Optical filter

8 Synthesizer

9 Electrical amplification machine

10 Light branching machine

11 Clock extraction machine

12 Phase converter

13 The optical fiber for optical-pulse compression

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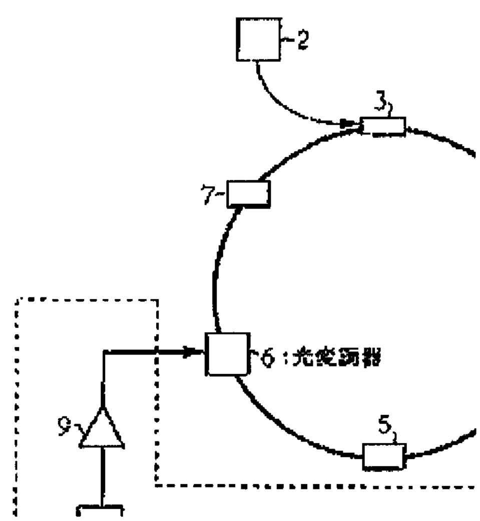
(54)【発明の名称】　レーザパルス発振器

(57)【要約】
【目的】　高繰り返しの光パルス列を長時間にわたって極めて安定に発生させるレーザパルス発振器を提供する。
【構成】　レーザ共振器内に設置された光変調器６の変調周波数がレーザ共振器のループ長で決まる基本周波数の整数倍に設定された高調波モード同期レーザパルス発振器において，そのレーザの出力の一部から受光素子と狭帯域フィルターにより構成されるクロック抽出器１１によってその繰り返しに相当するクロック信号を抽出し，このクロック信号により光変調器６を駆動する。



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【特許請求の範囲】

【請求項１】　光変調器を含んだループにより構成され、該ループのループ長に対応した基本周波数の整数倍の繰り返し周波数のレーザパルスを出力するレーザパルス発振器において、

前記ループから得られるレーザパルスを電気信号に変換する受光素子と、該電気信号から前記基本周波数の整数倍の周波数のクロック信号を抽出する狭帯域フィルタとを有し、

該クロック信号を変調信号として前記光変調器に供給することを特徴とするレーザパルス発振器。

【請求項２】　前記ループ内に光パルス圧縮用光ファイバを含むことを特徴とする請求項１記載のレーザパルス発振器

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は、例えば、超高速光通信システムを構築するために必要となる繰り返し周波数の高いレーザパルスを、安定に発生させるレーザパルス発振器に関するものである。

【０００２】

【従来の技術】近年、モード同期技術を利用した光ファイバレーザにより、繰り返し周波数の高いレーザパルスを発生させる研究が盛んに行われている。図４は、従来のレーザパルス発振器の構成図の一例である。図において、１は希土類元素を添加した光ファイバ（以下希土類添加光ファイバと記す）、２は希土類添加光ファイバを励起するための励起光源、３は励起光を希土類添加光ファイバに結合させる光結合器、４は出力を取り出す光分岐器、５は光の進行方向を１方向に制限する光アイソレータ、６は光変調器、７は光フィルタ、８はシンセサイザ、９は電気増幅器である。

【０００３】このレーザパルス発振器において、繰り返し周波数の高い光パルスは次のようにして発生する。希土類添加光ファイバ１を光結合器３を通して励起光源２で励起すると、光フィルタ７の透過帯域内で、光アイソレータ５の順方向に連続光の発振が起こる。次に、シンセサイザ８から出力される電気信号を電気増幅器９を通して、光強度変調器６に印加する。一般に、共振器長（このレーザパルス発振器のループ長さ）をＬ、光ファイバの屈折率をｎ、光速をｃとすると、共振器長で決まる基本周波数f_0＝ｃ／（ｎＬ）で変調を加えた場合、基本周波数f_0でのモード同期が実現され、安定な光パルス列が発生できる。

【０００４】また、変調周波数をレーザの共振器長で決まる基本周波数f_0のｑ倍、ｑf_0＝ｑｃ／（ｎＬ）（ｑは整数）に設定すると、基本波のｑ倍の周波数で発振する高調波の強制モード同期が実現できる。すなわち、レーザの共振器内にｑ個の光パルスが等間隔に作られ、高次の変調周波数に一致した繰り返しをもつ光パルス列が発生する。この光パルス列は、光分岐器４を通して出力される。例えば、レーザの共振器長が２００ｍであるとき、共振器長で決まる基本周波数f_0は１ＭＨｚであるが、変調周波数を、ｑ＝１００００とし、１０ＧＨｚに設定すると、１０ＧＨｚの繰り返しをもつ光パルス列が発生する。

【０００５】

【発明が解決しようとする課題】しかしながら、かかる従来のレーザパルス発振器においては、レーザ共振器内の温度変動により共振器長が変動し、その結果として基本波が時間とともに変化する。その一方、印加する高次変調信号の繰り返しは一定値に設定されるので、両者の繰り返しが一致せず、長時間にわたって安定に光パルス列を発生させることが困難であった。

【０００６】ここで、レーザ共振器内の温度がΔｔだけ変化した場合を考える。温度がΔｔだけ変化すると、光ファイバ長はΔＬだけ変化する。この場合、ΔＬは次の式で与えられる。

$$\Delta L / L = \alpha \Delta t \qquad (1)$$

ただし、Ｌは温度変動以前のレーザの共振器長、αは光ファイバの線膨張率である。温度変動により、レーザの共振器長が変化すると、共振器長で決まる基本周波数f_0が変化する。この場合、変調周波数は基本周波数f_0のｑ倍に一致しなくなり、光パルスの波形が歪み高調波モード同期が実現できなくなる。周波数ｆ（＝ｑf_0）を温度変動以前の変調周波数とすると、周波数変動Δｆは次の式で与えられる。

$$\Delta f / f = \Delta L / L = \alpha \Delta t \qquad (2)$$

温度が変化したとき、高調波モード同期を達成するには変調周波数をΔｆだけ変化させることが必要となる。周波数変動Δｆは変調周波数ｆが大きくなるほど、すなわち、ｑの値が大きくなるほど大きくなる。つまり、高次の高調波モード同期ほど、温度変動による周波数の絶対変化量が大きくなり、長期間にわたって安定に光パルス列を得ることが困難である。

【０００７】例えば、上記の従来のレーザパルス発振器において、共振器内の温度が０．０１度変化した場合、Ｌ＝２００ｍ、ｆ＝１０ＧＨｚ、$\alpha = 10^{-5}$とすると、（１）、（２）式よりΔＬ＝２０μｍ、Δｆ＝１ｋＨｚになる。つまり、僅かな温度変動で、大きな周波数変動が生じ、光パルスの波形は劣化する。安定な光パルス列を得るためには、変調周波数をΔｆだけ変化させ、１０．０００１ＧＨｚにする必要がある。また、これを実現するためには、共振器の長さを自動的に調整するアクティブな負帰還回路を必要とする。

【０００８】また、高調波モード同期においては、共振器長で決まる基本周波数f_0のｑ倍で変調をかけているため、ｑが大きくなると基本周波数f_0によって決まる

縦モードのスペクトル成分を完全に抑制することが難しくなる。例えば、f_0 = 1 MHz、f = 10 GHzとし、従来のレーザパルス発振器で高調波モード同期を行った場合の光スペクトルを図5に示す。図において、強度が最も強い成分が10GHz毎にあるが、それ以外にも基本周波数f_0で決まる弱い縦モードのスペクトル成分がある。この変調周波数以外の縦モードのスペクトル成分は抑制されていないため、変調周波数と共振器長とのずれが発生するとともに、レーザの発振を不安定にし、光パルスを安定に発生させることを困難にする。

【0009】以上のように、従来の技術では高調波モード同期を行った場合、繰り返し周波数の高い光パルス列は発生するものの、共振器内の温度変動により短時間でパルス波形が劣化し、繰り返し周波数の高い光パルス列を長時間にわたって安定に発生させることは困難であった。また、光変調を行うための高安定なシンセサイザを必要とした。

【0010】本発明は、このような事情に鑑みてなされたもので、高調波モード同期において、高周波のシンセサイザやアクティブな負帰還回路を必要とせず、繰り返し周波数の高い光パルス列を長時間にわたって極めて安定に発生させるレーザパルス発振器を提供することを目的とする。

【0011】

【課題を解決するための手段】請求項1記載のレーザパルス発振器は、上記課題を解決するために、光変調器を含んだループにより構成され、該ループのループ長に対応した基本周波数の整数倍の繰り返し周波数のレーザパルスを出力するレーザパルス発振器において、前記ループから得られるレーザパルスを電気信号に変換する受光素子と、該電気信号から前記基本周波数の整数倍の周波数のクロック信号を抽出する狭帯域フィルタとを有し、該クロック信号を変調信号として前記光変調器に供給することを特徴とする。

【0012】請求項2記載のレーザパルス発振器は、請求項1記載のレーザパルス発振器において、ループ内に光パルス圧縮用光ファイバを含むことを特徴とする。

【0013】

【作用】請求項1記載のレーザパルス発振器によれば、受光素子は、任意に繰り返し周波数が変動しているレーザパルスを電気信号に変換する。狭帯域フィルタは、この電気信号から前記基本周波数の整数倍の周波数のクロック信号を抽出する。そして、ループ内の光変調器は、このクロック信号を変調信号としてレーザパルスを強度変調する。これによって、温度変動により共振器長が変化してレーザパルスの繰り返し周波数が変化しても、レーザパルスの繰り返しに追随した周波数で最適に光変調器を駆動することができる。したがって、温度変動によるレーザパルス波形の劣化がなく、長時間にわたって安定にレーザパルスの発振が継続する。

【0014】請求項2記載のレーザパルス発振器によれば、光ソリトンの効果を用いて発生するレーザパルスのパルス幅を短くすることができる。

【0015】

【実施例】以下、図1ないし図3を参照して、本発明によるレーザパルス発振器の一実施例について詳細に説明する。ただし、図4に示した構成と同一部分には同一符号を付した。図1は本実施例のレーザパルス発振器の構成を示す図である。図において、レーザパルス発振器は、希土類添加光ファイバ1、希土類添加光ファイバ1を励起するための励起光源2、励起光を希土類添加光ファイバ1に結合させる光結合器3、出力を取り出す光分岐器4、光の進行方向を1方向に制限する光アイソレータ5、光変調器6、光フィルタ7、光分岐器10、クロック抽出器11、移相器12、および電気増幅器9から構成される。

【0016】クロック抽出器11は、入力されたレーザパルスを電気信号に変換する受光素子と、中心通過周波数が10GHzに設定された狭帯域フィルタ、およびこの狭帯域フィルタの出力を増幅する電気増幅器から構成されている。ここで、本実施例のレーザパルス発振器のループ長は、基本周波数f_0が1MHzとなるように設定されている。また、クロック抽出器11は、基本周波数f_0の10000倍、つまり、繰り返し周波数が10GHzのレーザパルスを出力するように、狭帯域フィルタの中心通過周波数が10GHzに設定されている。

【0017】移相器12は、クロック抽出器11の出力信号の位相を調整する。電気増幅器9は、移相器12の出力信号を増幅し、光変調器6に供給する。光変調器6は、強度変調器であり、例えば、ニオブ酸リチウム製のマッハツェンダ型強度変調器などを用いることができる。つまり、本実施例のレーザパルス発振器では、図1の点線で示すように、クロック抽出器11から光変調器6まで閉ループを構成する。希土類添加光ファイバ1としてエルビウム添加光ファイバを用いると、レーザの発振波長は1.5μm帯となる。励起光源2としては、半導体レーザを用いることができる。

【0018】次に、上記構成のレーザパルス発振器における繰り返し周波数の高い光パルス列の発生について説明する。希土類添加光ファイバ1を光結合器を通して励起光源2で励起すると、光フィルタ7の透過帯域内で、光アイソレータ5の順方向に連続的なレーザ光の発振が起こる。このレーザ光を光分岐器4を通して取り出し、さらに光分岐器10で分け、その一部をクロック抽出器11に入力する。クロック抽出器11は、10GHz付近の縦モードによるクロック信号を抽出する。このクロック信号は、移相器12において位相調整され、電気増幅器9によって増幅された後、変調信号として光変調器6に供給される。光変調器6は、このクロック信号によってレーザ光を強度変調してレーザパルスを出力する。

【0019】ここで、共振器のループ長によって決まる基本周波数f_0のq倍に一致しない10GHz付近の縦モードによるクロック信号は、安定な光パルス列を発生できないため、クロック抽出過程において消滅する。しかし、基本周波数f_0のq倍に一致したクロック信号は、変調周波数と光パルスの繰り返しが完全に一致するため、安定な光パルスの発振が徐々に強められる。これが繰り返されると、最初は雑音的であった基本周波数f_0のq倍に一致したある1つの10GHz付近のクロック信号だけが残る。すなわち、余分な縦モードを抑制した1つのクロック信号だけで光変調器6を駆動するようになり、10GHzの高調波モード同期が達成される。＊

＊【0020】このとき、例えば、図2に示すように、希土類添加光ファイバ1と光分岐器4の間に光パルス圧縮用光ファイバ13を挿入することにより、光ソリトンの効果を用いて発生する光パルスのパルス幅を短くできる。ここで、光ソリトンについて説明する。光ソリトンとは光ファイバの負の分散によるパルス幅の広がりと、自己位相変調効果によるパルス幅の圧縮とがつりあうことにより発生する安定な光パルスであり、光ファイバ中を波形をかえることなく伝搬するという特徴をもっている。N＝1の標準ソリトンを作るのに必要なピーク強度$P_{N=1}$は次の式で与えられる。

$$P_{N=1} = 0.776 \pi \lambda^3 w^2 |D| / \pi^2 c n_2 \tau^2 \qquad (3)$$

ここでDは光ファイバの波長λにおける群速度分散、cは光速、n_2は非線形屈折率、τはパルス幅、wは光ファイバのスポットサイズの大きさである。

【0021】すなわち、光パルス圧縮用光ファイバ13の群速度分散Dを負にすることによって光ソリトンを発生させ、パルス幅が広がらない光パルスを得ることができる。例えば、群速度分散D＝－3ps／km／nm、パルス幅τ＝3ps、スポットサイズの大きさw＝3μm、波長λ＝1．55μmとすると標準光ソリトンを作るのに必要なピーク強度は（3）式より約290mWとなる。光パルスの繰り返しを10GHzとすると、共振器内の平均強度は約8．7mWになる。この程度の強度は本実施例によるレーザパルス発振器内で容易に発生できる。つまり、光パルス圧縮用光ファイバ13として、波長1．55μmにおける分散値が－3ps／km／nmである分散シフトファイバを用いることにより、10GHzの繰り返しで、パルス幅が3psである光パルス列を安定に発生できる。この光カパルスの繰り返し周波数を変化させるには、クロック抽出器11で抽出されるクロック信号の周波数を変えればよい。

【0022】本実施例のレーザパルス発振器においては、温度変動により共振器長が変化し、光パルスの繰り返しが変化しても、光パルスの繰り返しに同期したクロック信号で変調を行うため、変調周波数と光パルスの繰り返しの間にずれが生じない。したがって、従来の技術と違い、温度変動によって光パルスの波形が劣化しない特徴をもつ。ただし、光パルスの繰り返しは共振器長の変動に応じてわずかに変化している。すなわち、本実施例のレーザパルス発振器は、共振器内の温度変動に依存せず常に高調波モード同期が維持され、長時間にわたって安定な繰り返し周波数の高い光パルス列を発生させることができる。さらに従来必要とした高精度なシンセサイザや共振器の安定化のためのアクティブな負帰還回路が不要となるため、経済的な利点も大きい。

【0023】また、高調波モード同期を行う際に、レーザの発振繰り返し周波数と変調器へ印加する変調周波数がいつも完全に一致しているので、変調周波数以外の余分な縦モードを完全に抑制できる。例えば、f_0＝1MHz、f＝10GHzとして、高調波モード同期を行った場合の電気スペクトルを図3に示す。図においては、10GHzの変調周波数成分だけが存在している。このように、変調周波数以外の余分な縦モードが完全に抑制できるため、安定した高調波モード同期が実現でき、繰り返し周波数の高い極めて安定な光パルス列を発生できる。

【0024】

【発明の効果】以上、説明したように、本発明によれば、高調波モード同期により繰り返し周波数の高い光パルス列を発生させるレーザパルス発振器において、従来必要としていた高精度なシンセサイザを必要とすることなく、レーザの出力の一部から繰り返し周波数に対応する正弦波のクロック信号を抽出し、その周波数により光変調器を駆動することにより、長時間にわたって極めて安定な繰り返し周波数の高い光パルス列を発生できる。また、レーザ共振器内に光パルス圧縮用光ファイバを挿入することによって、パルス幅の短い光パルスをさらに安定に発生することが可能である。

【図面の簡単な説明】

【図1】本発明のレーザパルス発振器の第1の構成例を示す図である。

【図2】本発明のレーザパルス発振器の第2の構成例を示す図である。

【図3】本発明のレーザパルス発振器における電気スペクトルの様子を示す図である。

【図4】従来のレーザパルス発振器の構成を示す図である。

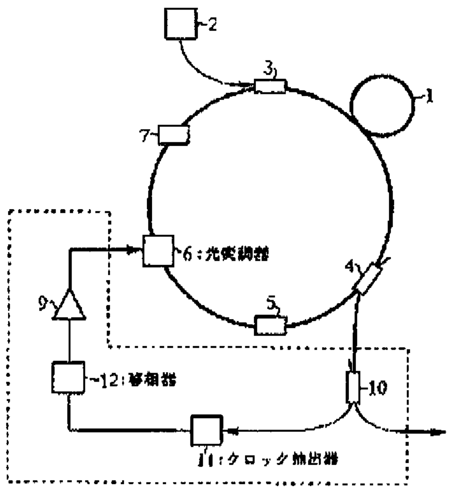
【図5】従来のレーザパルス発振器における光スペクトルの様子を示す図である。

【符号の説明】

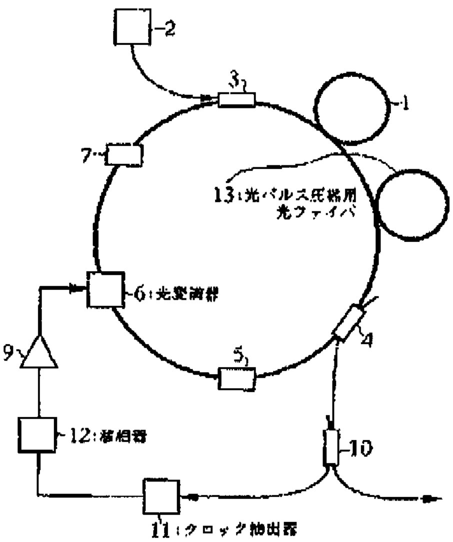
1 希土類添加光ファイバ
2 希土類添加光ファイバを励起するための励起光源
3 励起光を希土類添加光ファイバに結合させる光結合器
4 出力を取り出す光分岐器

5 光の進行方向を１方向に制限する光アイソレータ
6 光変調器
7 光フィルタ
8 シンセサイザ
9 電気増幅器
＊10 光分岐器
11 クロック抽出器
12 移相器
13 光パルス圧縮用光ファイバ

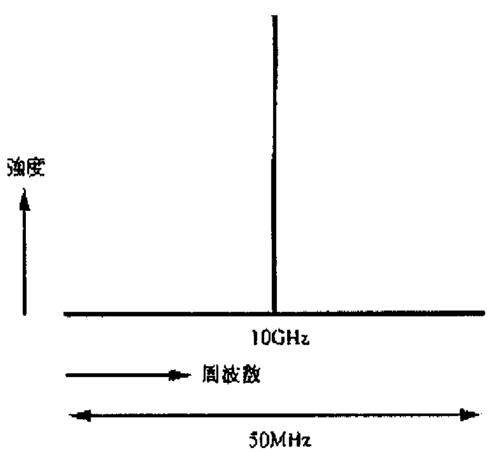
【図１】



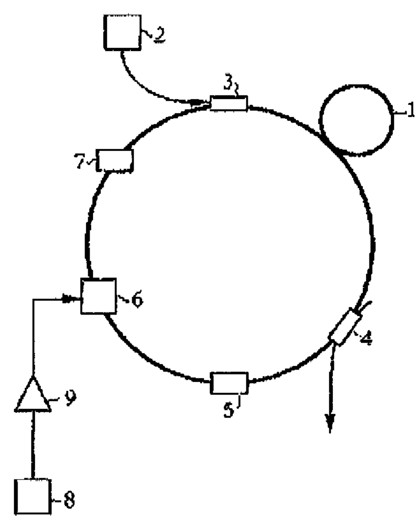
【図２】



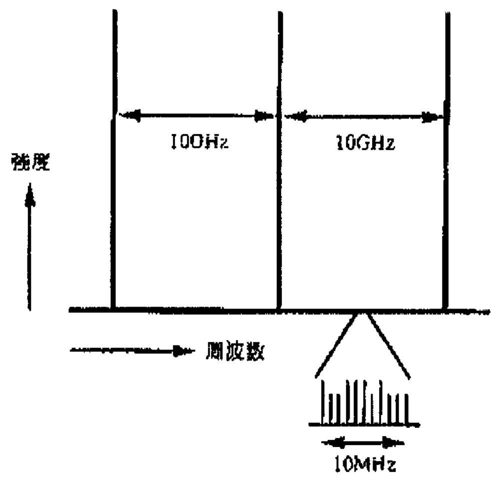
【図３】



【図４】



【図5】



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